



# Intelligent Elements for ISHM

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# Abstract

We define a *smart* element to have the capability of supporting networked implementations of IEEE 1451.x smart sensor and actuator protocols. We further define an *intelligent* element as a smart element with that has sufficient computing capacity to support anomaly detection or other algorithms in support of ISHM functions.

The ISHM group at SSC has been actively developing intelligent elements in conjunction with several partners at other Centers, universities, and companies as part of our ISHM approach for better supporting rocket engine testing. We have developed several implementations. Among the key features for these intelligent sensors is support for IEEE 1451.1 and incorporation of a suite of algorithms for determination of sensor health. In order to bring the benefits of intelligent sensors to existing data acquisition environments, we have also developed virtual implementations of intelligent sensors.



# Motivation for the Work

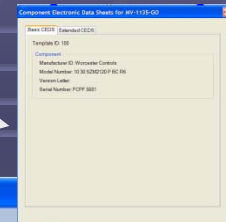
There are a number of architecture models for implementing Integrated Systems Health Management (ISHM) capabilities. For example, approaches based on the OSA-CBM and OSA-EAI models, or specific architectures developed in response to local needs. NASA's John C. Stennis Space Center (SSC) has developed one such version of an extensible architecture in support of rocket engine testing that integrates a palette of functions in order to achieve an ISHM capability. Among the functional capabilities that are supported by the framework are: prognostic models, anomaly detection, a data base of supporting health information, root cause analysis, and integrated awareness. Especially promising are the roles that smart and intelligent elements can assume in ISHM architectures.



# Composite View of an ISHM Application

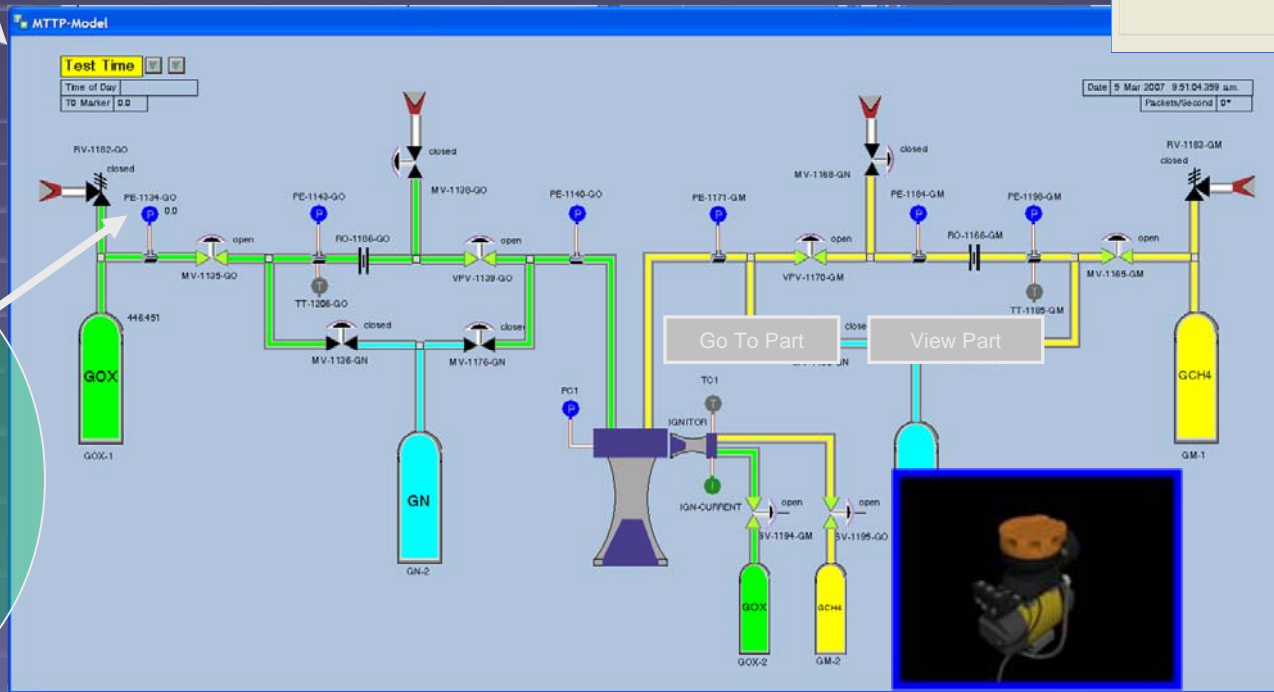
**ISHM Models (Embedded Data, Information, and Knowledge):**  
MTTP Implementation

**Health Assessment Database:**  
Health Electronic Data Sheets  
Repository of anomalies



**Anomaly Detection:**  
Leaks, etc.

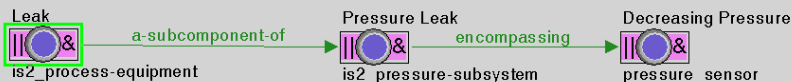
**Intelligent Sensors:** IEEE Standard+Health



**Embedding of Predictive Models**

**Root Cause Analysis**

**Integrated Awareness:**  
3-D Health Visualization of MTTP





# Role of Intelligent Elements in ISHM

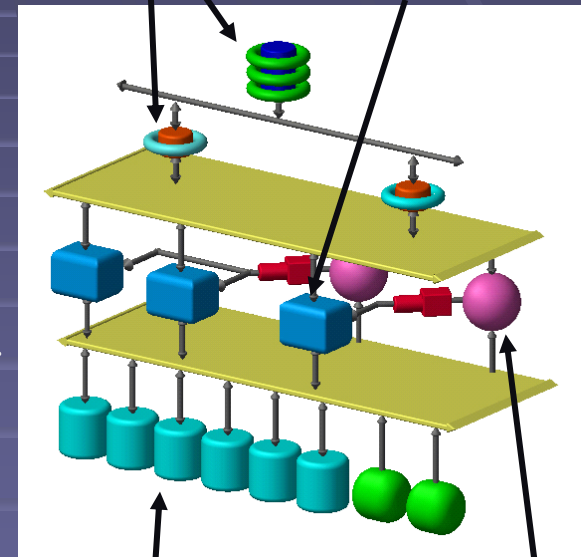
- Smart sensors
  - NCAP (Go Active, Announce)
  - Publish data
  - Set/Get TEDS
- Intelligent sensors
  - Set/Get HEDS
  - Publish health

Detect classes of anomalies using:

- Statistical measures
  - Mean
  - Standard deviation
  - RMS
- Polynomial fits
- Derivatives (1<sup>st</sup>, 2<sup>nd</sup>)
- Filtering—e.g., Butterworth HP
- FFT—e.g., 64-point
- Algorithms for
  - Flat
  - Impulsive (“spike”) noise
  - White noise
- Intelligent Actuators—e.g., Valves

Intelligent (Sub)Systems

Intelligent Processes



Intelligent Actuators

Intelligent Sensors



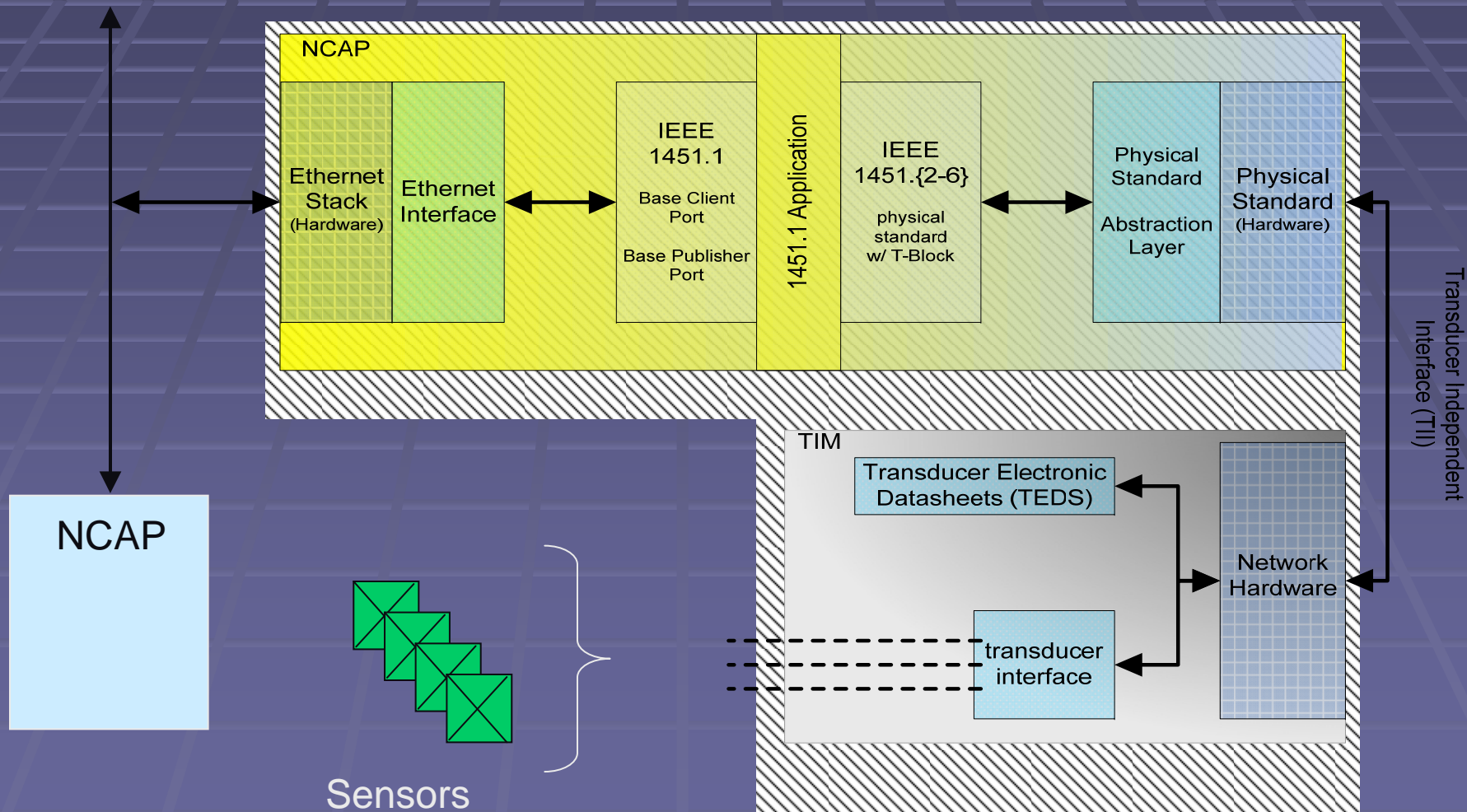
# IEEE 1451.X Smart Sensor Standards

- IEEE 1451.0 Defines a set of common commands, operations and Transducer Electronic Data Sheets (TEDS) for the family of IEEE 1451 standards
- IEEE 1451.1 Defines a common object model describing the behavior of a Network Capable Applications Processor (NCAP)
- IEEE 1451.2 Defines a transducer to NCAP transducer independent interface (TII) and TEDS for a point-to-point configuration of transducer interface modules (TIMs)
- IEEE 1451.3 Defines a transducer to NCAP interface and TEDS for multi-drop transducers
- IEEE 1451.4 Defines a mixed-mode interface for analog transducers with analog and digital operating modes; simplest 1451 model
- IEEE 1451.5 Defines a TII interface and TEDS for wireless transducers
- IEEE P1451.6 Defines a TII interface and TEDS using the controller area network (CAN)
- IEEE P1451.7 Defines an RFID interface





# Block Diagram of a Smart Sensor





# Key Element of a Smart Sensor: TEDS

- The transducer electronic data sheet (TEDS) provides the means to tag a sensor with descriptive information including
  - Manufacturer
  - Serial number
  - Calibration status
  - Coefficients
  - Physical location
- BENEFIT: Offers practical means for reducing costs/errors associated with measurement system configuration





# Making a Smart Sensor Intelligent

- Embed algorithms for ISHM
  - Sensor health detection
    - Opens/shorts
    - Debondment
    - Etc.
- Adapt IEEE 1451.x standards
  - Publish normal data + health
  - Extend TEDS to generalized xEDS
    - Health electronic data sheet (HEDS)
      - Set\_HEDS, Get\_HEDS
    - Component electronic data sheet (CEDS)
      - Set\_CEDS, Get\_CEDS



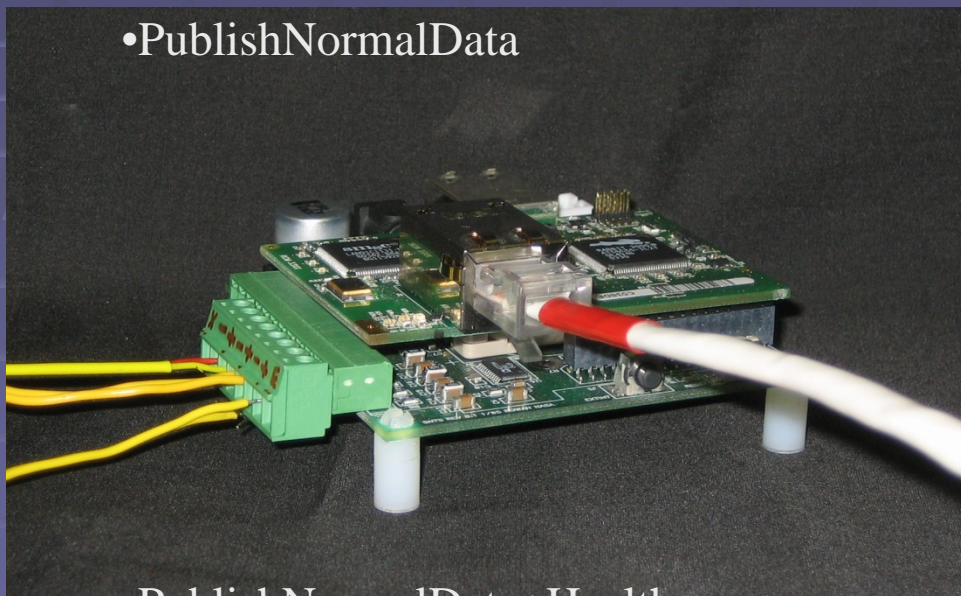
# Example ISHM-Enabled Intelligent Sensors

## IEEE 1451 & O/S

- NCAPBlock\_Go\_Active
- NCAP\_Block\_Go\_InActive
- Request\_NCAPBlock\_Announcement
- NCAPBlock\_Announcement
- PublishNormalData

## Hardware

- 3-Ch Thermocouple
- 24-bit ADC
- 8-bit  $\mu P$
- 1 MB RAM/Flash
- SPI
- Ethernet (802.3af)



- PublishNormalData+Health
- Channel\_Sample\_Rate
- Get\_HEDS •Set\_HEDS •Get\_TEDS •Set\_TEDS

## ISHM

- Mean, Std dev, Min/Max, RMS
- $dv/dx$ ,  $d^2v/dx^2$
- Poly fit
- Bu HPF (13<sup>th</sup>)
- 64-pt FFT
- Anomalies: Flat, Spike, Noise



# Other Smart Sensors—Some w/ Intelligent Sensor Capabilities



Mobitrum

[www.mobitrum.com](http://www.mobitrum.com)



Smart Sensor Systems

[www.smartsensorsystems.com](http://www.smartsensorsystems.com)



NIST

[www.mel.nist.com](http://www.mel.nist.com)



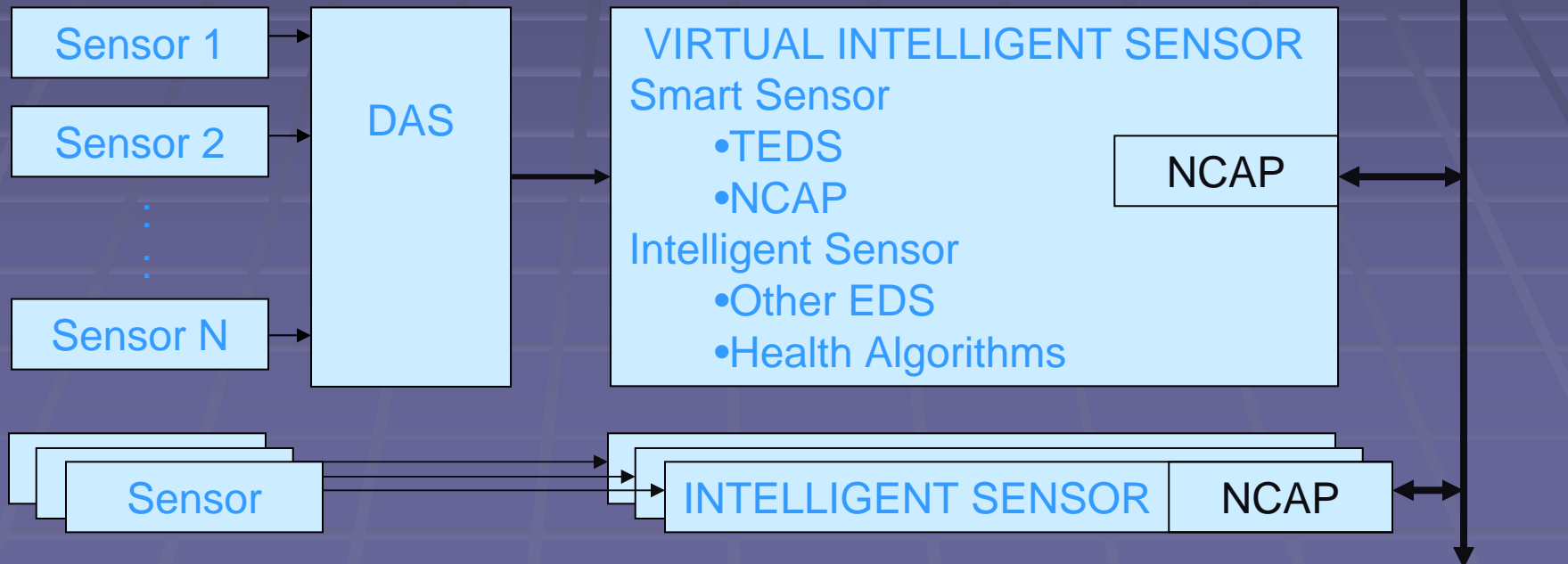
Esensors

[www.eesensors.com](http://www.eesensors.com)



# ISHM Enabling Technologies: Intelligent Sensors

- To realize IS benefits in a system populated with conventional sensors, create a Virtual Intelligent Sensor Environment (VISE)
- The VISE is software that mimics IS behavior and allows use of conventional sensors and data acquisition systems





# Conclusions

- Smart sensors offer important cost benefits associated with ease of configuration and maintenance
- Intelligent sensors offer benefits of embedding ISHM algorithms to allow distributed processing